Identifying Technology Barriers to the Realization of True Microrobots and Nanorobots for Military Application by 2035

Introduction

When most people consider the term "microrobots," especially in conjunction with military use, the common perception is of "small" autonomous robots (including unmanned aerial vehicles) on the order of one to two feet in length used in reconnaissance applications.[1] This common perception is also exemplified in the Air Force Research Laboratory's (AFRL) third focused-long-term-challenge (FLTC-3) bird-sized and insect-sized micro air vehicle (MAV) concepts for demonstration targeted in 2015 and 2030, respectively.[2] However, this research deals with the concepts of "true" microrobot and nanorobot use in military applications; "true," meaning that the robots are of micrometer and nanometer proportions, respectively.

The main goal of this research is to identify key technological barriers to the development of true microrobots and nanorobots for use in military applications by 2035. However, the primary focus will be towards microrobots. Another goal of this research is to explore whether or not the key technical barriers are likely to be overcome in order to realize practical microrobots and nanorobots by 2035. Additionally, an argument will be made that the Department of Defense (DOD) should still sponsor research and development of both microrobots and nanorobots even if their realization by 2035 is unlikely. This sponsorship is a critical catalyst for driving both the miniaturization and integration of sensors, communication systems, propulsion systems, munitions, control systems, power supplies, and packaging for use in realizing the more achievable bird-sized systems such as AFRL's FLTC-3 MAVs. The next section describes the research methods and the proposed organization of the final paper, and the organization of the rest of this essay.

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14. ABSTRACT
This paper is an initial investigation of the feasibility of micrometer and nanometer sized robots for military applications in the year 2035

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Research Methods and Final Paper Organization

The final research paper will begin with an introduction similar to the one presented above. Next, a brief background on the current state of micro- and nanorobots will be given in order to orient the reader. Next, concept of operations (CONOPs) for both micro- and nanorobots will be proposed. The CONOPs will be in the form of four-quadrant futures scenarios (discussed later in this paper), and be used to later define required robot technologies and potential environmental challenges. The CONOPs will also facilitate backcasting, and incorporate environmental scanning results of any other relevant CONOPs from the Air Force, Army, Navy, or other sources. Following this, a relevance tree of the required technologies and components necessary for the robots envisioned in the CONOPs will be constructed. Environmental scanning of DOD and public technical literature will be used to assess the availability of the required technologies and components, and identify technical barriers to realization by 2035. The final paper will end with conclusions about the feasibility of micro- and nanorobots by 2035 and recommendations for the DOD's involvement with relevant funding for research and development. The remainder of this essay is organized along the same structure of the final paper.

Background

For this research, a microrobot is defined as a robot with length on the order of 1×10^{-6} meters (one micrometer or micron) or a robot constructed from components of micron proportions. Therefore, a microrobot could range in size from 1 micron to a few millimeters in length. For size perspective, the diameter of a human hair is approximately 100 microns, and the diameter of a human red blood cell is 7 microns. From the perspective of a macro-world

observer, a land, aerial, or aquatic based microrobot would appear at its largest as an ant, gnat, or plankton, respectively; and at its smallest, appear invisible. A nanorobot is defined as a robot with length on the order of $1x10^{-9}$ meters (one nanometer) or a robot constructed from components of nanometer proportions. Therefore, a nanorobot could range in size from 1 nanometer to a few microns in length. For size perspective, the spacing between crystalline silicon atoms is 0.543 nanometers, and molecules are of nanometer size. From the perspective of a macro-world observer, a nanorobot would appear invisible.

To date, crude microbots and microrobot components suitable for crawling[3], flying[4], and swimming[5] have been demonstrated for potential use in close quarters inspection, medical, and micro/nano-nanometer manipulation/assembly applications.[6,7] The most integrated microrobot to date is that of Hollar et al. consisting of an integrated actuator foot, control circuitry, and solar cell, and was able to demonstrate crude uncontrolled movement on the order of microns/minute speed.[8] Nanorobots, proposed by Drexler as "universal assemblers," with the ability to re-order atoms "with the precision of programmed machines," have not yet been demonstrated in any aspect.[9]

Microrobot and Nanorobot CONOPs

Credible scientific research in microrobot and microrobot enabling technology has been conducted since the late 1980s[10] (including early 1990s Defense Advanced Research Project Agency (DARPA) sponsored research[11]). Surprisingly, however, there exists no coherent work outlining CONOPs for microrobots' or nanorobots' use in military applications to this date[12] (with a possible exception[13]). The final paper will outline two novel sets of four futures scenarios CONOPs for micro- and nanorobots, respectively, as shown in Figure 1. With reference to Figure 1, "independent" implies each individual robot contains all the component

functions necessary to conduct a mission alone, whereas "distributed" implies different component functions will be distributed amongst several robots in order to conduct a mission. "Remotely piloted" implies that the robot will be remotely controlled during the mission, whereas "artificial intelligence" implies the robot will seek and reconnoiter the target autonomously throughout the mission.

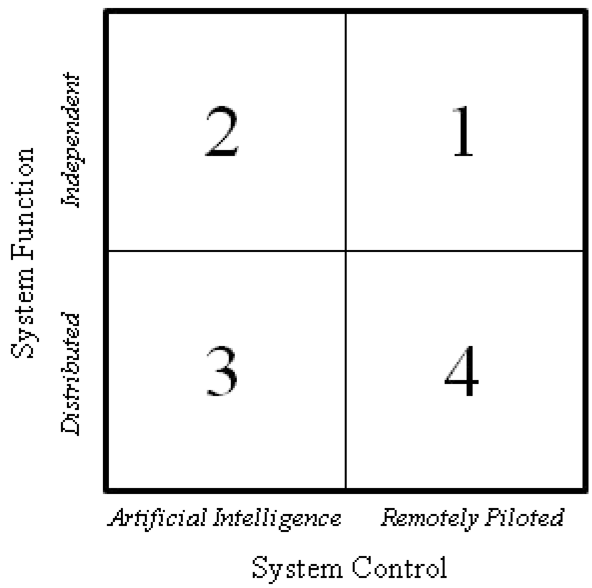

Figure 1: Four-quadrant futures scenario CONOPs for micro- and nanorobots.

The CONOPs will describe concepts such as the specific mission, communication techniques, stealth, enemy countermeasures and detection capability, weapon effect estimates, ingress procedures, egress procedures or self destruction, maintenance, combined arms, artificial intelligence (complex or rudimentary seeking-behavior based), and the mission environment. A brief example of military CONOPs, touching on quadrants 1 and 4 for microrobots, and quadrant 2 for nanorobots (with respect to Figure 1), follow directly from the aforementioned commercial applications of close quarters inspection, medical, manipulation, and assembly. Whether the robots operate as isolated entities, *en masse*, or in a distributed sense, or whether they operate in

the domains of land, air, water, or space the operations will be similar. Ideally, the microrobots will require capabilities like today's Global Hawks and Predators. Nanorobots will probably be utilized like "man-made viruses" targeted against enemy material. Micro- and nanorobots, the ultimate in stealth due to their size, will be delivered to the target area either by themselves, a larger unmanned vehicle or microrobot, a kinetic projectile, or a human host. Microrobots will crawl, fly, float, or swim to their final targets through caves, ducts, and cracks. Once at their targets such as open areas of enemy activity, command posts, offices, hideouts, computer/weaponry circuit boards, antennas, satellites, etc. they will be used to gather intelligence, reconnoiter, release collective explosive charges or corrosives, reprogram equipment, or sabotage with plausible deniability. Nanorobots will render explosives and computer processors inert, reprogrammed, or reengineered. Micro- and nanorobots will probably not be used against humans because they will likely be classified as chemical or biological weapons, and thereby violate certain *jus in bello*.

Required Microrobot and Nanorobot Technologies and Components

In the final paper, relevance trees will be used to break down the microrobots and nanorobots required to fulfill the aforementioned CONOPs into required technologies and components. Figure 2 is a graphical example of a relevance tree for a microrobot corresponding to the quadrant 1 futures scenario CONOPs. Environmental scanning of technical literature will be used to assess the state-of-the-art for each component or technology depicted in the relevance tree. Analyses, extrapolations, and arguments will be made in order to assess the readiness of, or identify technical barriers with, each component and technology for use in realizing microrobots by 2035. Environmental scanning of Air Force, Army, and Navy research efforts' timelines will also be used to assess and bound the predicted estimates on microrobot realization, such as

AFRL's FLTC-3 bird-sized and insect-sized MAV concepts for demonstration targeted in 2015 and 2030, respectively.[14]

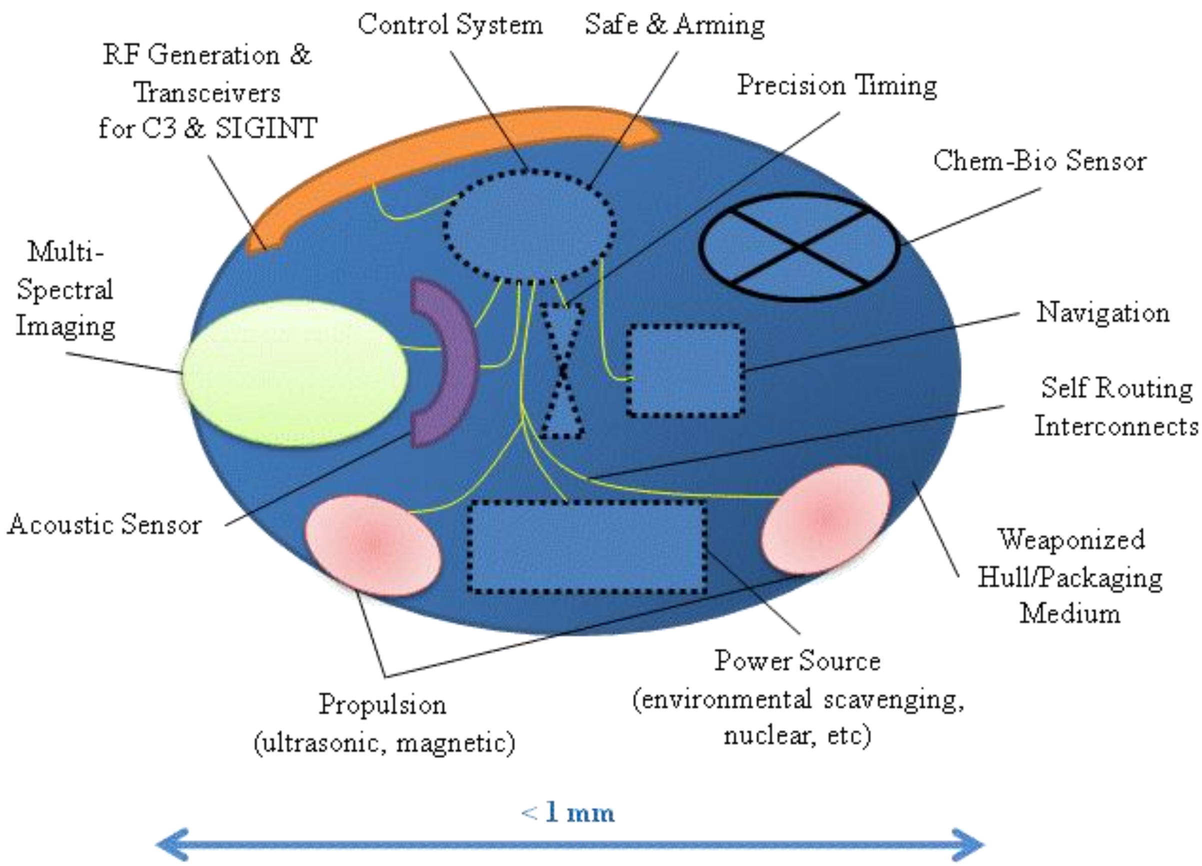

Figure 2: Microrobot relevance tree corresponding to a quadrant 1 futures scenario CONOPs.

Several technical barriers exist today that challenge the aforementioned CONOPs and relegate it to wishful thinking by 2035. With respect to microrobots, first and foremost is the inexistence of a suitable miniaturized power source in order to power the robot. Presently microrobots are powered using tethered wires, close proximity inductive coupling of large coils, or solar power – all impractical for long distance autonomous operations. Communication for remote control or intelligence and reconnaissance data telemetry via radio frequency (RF) or line of site optical will be impractical due to physical barriers at this small scale regarding antenna

efficiency, RF circuitry, loss of line-of-sight, and lack of transmission power to reach the outside world. Multispectral imaging will be rendered impractical because the robots are now on the order of size of a few or single pixels sensing elements. Even if operating in a distributed sense, where each robot represents one pixel, the inexistence of suitable miniaturized high precision position and timing subsystems for composite image correlation and construction renders imaging impossible. With respect to nanorobots, the same problems that will plague microrobots will be magnified by several orders of magnitude. Additionally, due to physics at this scale, remote communication and information storage will be impossible.[15] Nanorobots will have to be employed in an exclusively autonomous manner. Even if nanorobots are realizable, the energy required to break atomic bonds will render atomic rearrangement impractical.[16] Furthermore, even if the atomic rearrangement function is realized, the time required for nanoscale objects to complete the macroscale sabotaging transformation of enemy materials will be impractical.[17]

Finally, even if all the aforementioned technical barriers were overcome, nature presents itself as a final obstacle. Micro- and nano robot travel will be thwarted by wind, breezes, currents, surface tension of moist surfaces, repulsion or attraction of charged surfaces, and dust particles resulting either in being miles off course or completely halted. If micro- and nanorobots are expected to move or crawl along surfaces to reach their targets, the fractal lengthening of the travel surface's topology at the microscopic scale, will result in a never ending journey. A not currently known method of propulsion will have to be discovered in order to surpass nature.

Conclusion

In the final paper, the conclusion section will contain three elements: discussion of key technological barriers toward micro-nanorobot realization by 2035, technical proposals for

overcoming the key barriers, and an argument for DOD funding of research and development for micro-nanorobots even if key barriers are not overcome.

Based on present technical literature, cutting edge research is currently underway in the areas of miniaturized biological and chemical sensors, precision timing, navigation components, optical components and sensing elements, and acoustic sensors. Although some modest research is currently underway in self-assembly of micro and nano-scale objects, miniature power supplies, miniature RF components, micro-actuators for motion, disparate component technology integration, and packaging, these technologies represent key barriers, and will have to significantly evolve in order to realize a true micro- or nanorobot by 2035. Furthermore, even though microelectronics are already micro-sized, the silicon real-estate required for the processing, control, and memory for Global Hawk and Predator-like microrobots may prove too large to fit in a true microrobot. Prospects for overcoming these barriers may include nano-wire based RF systems and sensors, sonic propulsion systems, nuclear or bio-based environment scavenging power sources, self-routing nervous-system-like interconnects, and novel packaging/self-assembly mediums.

If these technical barriers are not overcome, insect-sized robots may be the only practical choice for 2035. However, technological advancements accrued through striving towards the goals of true micro- and nanorobots are critical towards the U.S. achieving a technological edge in more practical-sized small robots for military application. Thus, the U.S. should still sponsor research and development of both microrobots and nanorobots today.

Paul Kladitis

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